Non-Equilibrium Statistical Physics

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Motivation

Equilibrium Statistical Physics

- Well-defined framework
- Fluctuation-response relations for dynamics
- Changes of scale / coarse-graining straightforward

$$Z = \mathrm{Tr}\; e^{-\beta H} \rightarrow ?$$

Non-equilibrium Statistical Physics

- Many / most systems of interest **not** at equilibrium
- May take too long to equilibrate: transients matter, **aging**
- Or be **driven** from outside (biological systems), which breaks detailed balance (microscopic reversibility)
- Often no Hamiltonian, system defined purely by **dynamics** (e.g. agent-based models, network dynamics)
- Even this dynamical description may be **unknown**

Research Questions

- What general **frameworks** for non-equilibrium are there?
- How do we **change scale** or focus on **subsystems**?
- What **structures** and **behaviours** can non-equilibrium dynamics produce?
- How do we analyse systems with many different **timescales**?
- Can we **learn** dynamical models from data?

Techniques You Can Learn

- Path integrals (coherent states, Martin-Siggia-Rose)
- Trajectory thermodynamics, large deviation techniques
- Field-theoretic methods & simulations
- Cavity methods for networks
- Long-time scaling, stochastic simulation, molecular dynamics
- Random matrix theory

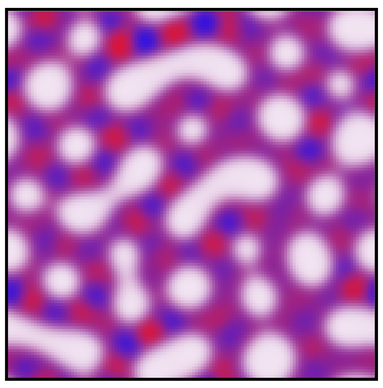
Areas for Bachelor Projects

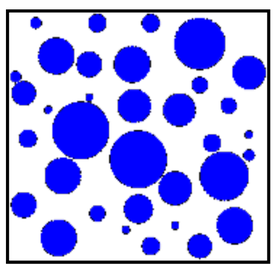
Active matter

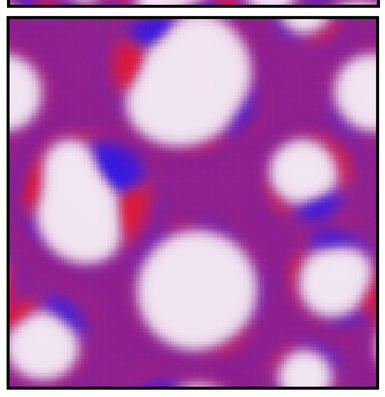
- Dynamics of dense active matter: Long-range correlations? Avalanches of rearrangements? Active doping?
- Non-reciprocal interactions: Multiple instability length scales in field theory, travelling states, oscillator systems
- Rheology of active matter, elastoplastic models
- Active processes in dynamics of polymer networks

Heterogeneity in networks

- Most biological / social networks are heterogeneous (some nodes have many neighbours, some few etc)
- How does this affect physical processes?
- Analytically solvable cases that "break" Wigner semicircle law, multifractal eigenvectors, ..

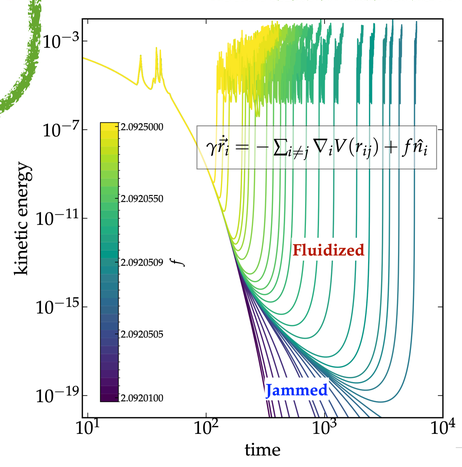


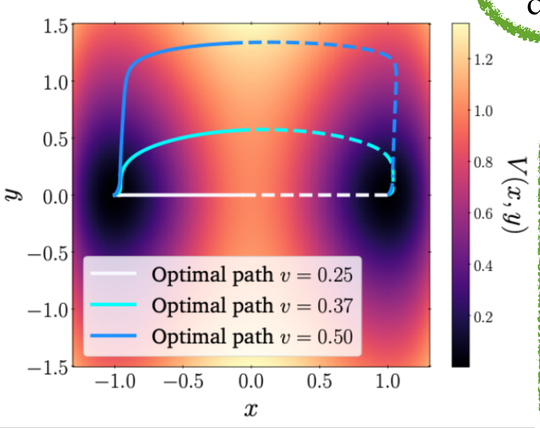


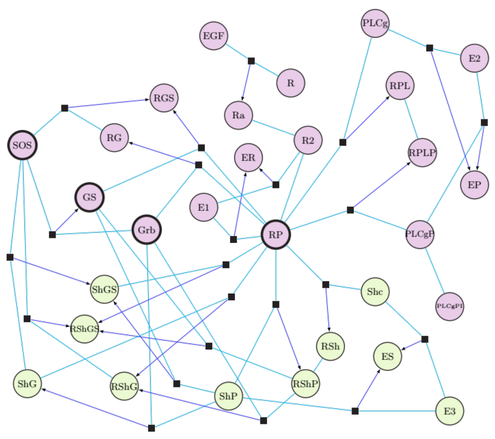


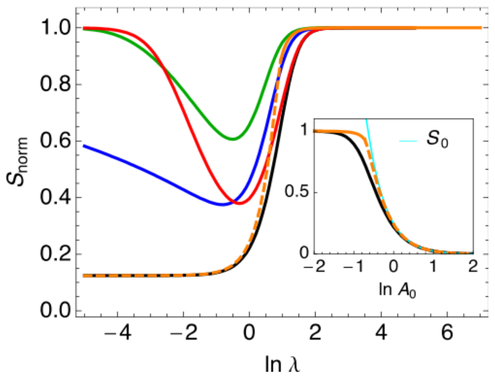
Path-based thermodynamics

- Study dynamical large deviations: trajectories with high current, activity
- Probe by biasing trajectory distribution: thermodynamics of fluctuating paths, dynamical phase transitions
- Interaction of driving (bias) and aging?







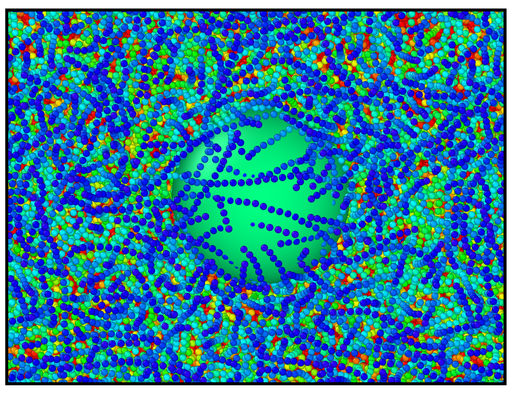


Dynamics with non-Gaussian noise

- Relevant in bacterial swimmer suspensions, granular gases, …
- Exact solutions in low noise limit
- Time for crossing potential barrier?
- Is non-Gaussian noise more efficient?
- Effects of activity (e.g. self-propulsion) and dimensionality?

Dynamics on networks

- Simple picture of amorphous material: hopping on network of metastable states
- Non-eq dynamics: competition of energetic (barriers) & entropic (connectivity) effects
- Analysis by random matrix theory, links to many-body localization, ...



Phase separation in complex mixtures

- Relevant in soft matter (colloids), biology (cytoplasm, lipid membranes)
- How do particle species redistribute between phases? Effect of crowding?
- Non-eq. structures by slow kinetics?
- Growth of competing phases?

Amorphous matter & rheology

- Amorphous materials (glass, sand, emulsions, biopolymers) trapped in metastable states
- Memory formation by shear/activity
- Effects of disorder & heterogeneity
- Relevant also for biophysics, e.g. in cytoskeletal rheology

